

Study of the X-ray emission mechanism of radio-loud narrow-line Seyfert 1 galaxy

H. Shirakawa and Y. Fukazawa, Y. Tanaka, R. Itoh and K. Kawaguchi
*School of Science, Hiroshima University, 1-3-1,
 Kagamiyama, Higashi-hiroshima, Hiroshima, Japan 739-8526*

1H0323+342 is one of narrow-line radio-loud Seyfert 1 galaxies (RL-NLS1), which is a new class of gamma-ray emitting AGNs. Narrow-line Seyfert 1 galaxies (NLS1) have a small-mass black hole, but its mass accretion rate is almost as high as Eddington limit. Therefore, by observing NLS1s, we can know the evolution of supermassive black holes at the center of galaxies. Some of NLS1s are radio-loud and we call them RL-NLS1. From past observations, multi-wavelength spectrum of RL-NLS1s is similar to that of typical blazars; the synchrotron emission in the lower energy band up to the optical band, and inverse Compton scattering of low energy photons from disk, torus, and broad line region. X-ray band is a transition region between the synchrotron and inverse Compton, and also there is a possible disk/corona emission. Therefore, we studied the energy-dependence of time variability of the X-ray emission of 1H0323+342, which have been observed by Suzaku in 2009 and 2013, in order to constrain the emission mechanism. We found that the lower energy below 1 keV and the higher energy above 7 keV show a different variability from the middle energy band, indicating at least two emission components in the X-ray band. X-ray spectrum is not a simple power-law, but requires an additional features; a broken power-law plus flat hard component, or a power-law plus a relativistic reflection component. Each spectral component seems to vary independently.

I. NALLOW-LINE RADIO-LOUD SEYFERT 1 GALAXY (RL-NLS1)

Narrow-line Seyfert 1 galaxy (NLS1) is a class of active galactic nuclei (AGN). The width of optical emission lines is narrower than that of Seyfert 1 galaxies, and NLS1s do not exhibit strong X-ray absorption like Seyfert 2 galaxy. In the X-ray spectrum, there is often a large soft-excess. NLS1s are identified by the following three characteristics.

1. FWHM ($H\beta$) $< 2000 \text{ kms}^{-1}$ (Goodrich 1989)
2. $[OIII] / H\beta < 3$ (Osterbrock & Pogge 1985)
3. strong permitted Fe II emission lines (Boroson & Green 1992)

NLS1s have a small-mass black hole, but its mass accretion rate is almost as high as Eddington limit (Marconi et al. 2008). We can study the evolution of supermassive black holes at the center of galaxies by observing NLS1s.

A. Nallow-line radio-loud Seyfert 1 galaxy (RL-NLS1)

Most of NLS1s are radio-quiet ($R < 10$, R : radio loudness, ratio of 5 GHz radio to B-band flux densities) (Kellermann et al. 1989), but 7 % of NLS1s are radio-loud ($R > 10$) and 2.5 % are very radio-loud ($R > 100$) (Komossa et al. 2006), and they are called as radio-loud narrow-line Seyfert 1 galaxies (RL-NLS1).

With early Fermi observation, GeV gamma-ray emission has been discovered from PMN J0948+0022, one of RL-NLS1s (Abdo et al. 2009a). After that, GeV gamma-ray emission was found from other three

RL-NLS1s (Abdo et al. 2009b), so it is found that RL-NLS1s generally emit GeV gamma-rays. From past observations, the multi-wavelength spectrum of RL-NLS1 is similar to that of typical blazars; the synchrotron emission in the lower energy band up to the optical band and the inverse Compton scattered X-ray and gamma-ray emission of low energy photons from disk, torus, and broad line region. X-ray band is a transition region between the synchrotron and the inverse Compton, and also there is a possible disk/corona emission.

As described above, X-ray emission mechanism of RL-NLS1s is uncertain. Therefore, we studied the energy-dependence of time variability of the X-ray emission of a RL-NLS1s 1H 0323+342, which have been observed by Suzaku in 2009 and 2013.

II. DATA ANALYSIS

A. Energy-dependence of time variability

Fig.1 is a light curve of 1H 0323+342 observed by Suzaku in 2013. 1H 0323+342 varies with a time scale of several ks, but the soft X-ray band below 1 keV shows a independent behavior from the other bands . Fig.2 shows correlations of count rates between 2–3 keV and other bands. The lower energy below 2 keV and the higher energy above 7 keV show a different variability from the middle energy band, suggesting that there are at least two spectral components in the X-ray band.

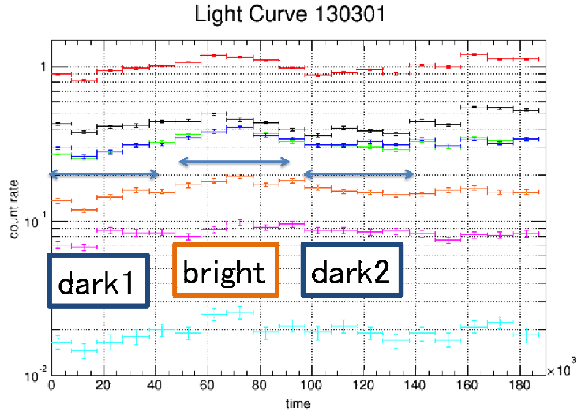


FIG. 1: Suzaku X-ray light curves of 1H 0323+342 in various energy bands. Band1 : 0.5–1 keV (black), band2 : 1–2 keV (red), band3 : 2–3 keV (green), band4 : 3–5 keV (blue), band5 : 5–7 keV (orange), band6 : 7–10 keV (magenta), band7 : Fe-k line region (cyan). Definition of bright and dark period is also shown for spectral analysis.

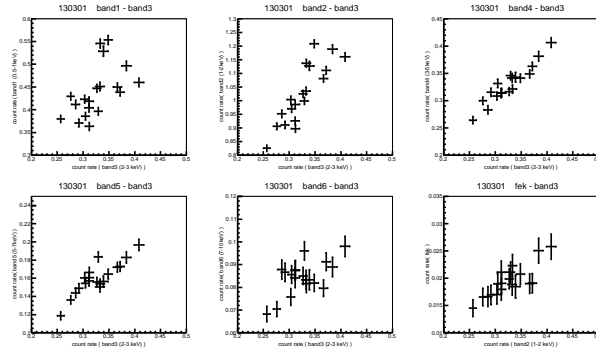


FIG. 2: Correlations of count rates between band3 (2–3 keV) and other energy bands in 2013

B. Spectral fitting

First, we fit the X-ray spectrum of 1H 0323+342 with the absorbed power-law model, but there remain residuals at the higher and lower energy region ($\chi^2/dof = 1017.26/528$) and thus the spectrum is not a simple power-law shape (Fig. 3).

1. Jet emission model

To reduce the residual in Fig.3, we added a broken power-law model. This model of one hard power-law and one broken power-law represents a jet emission of inverse Compton and synchrotron, respectively. As in Fig.4 and Fig.5, X-ray spectra can be fitted with this model for 2009 and 2013 (Table I). The breaking energy becomes around 0.7 keV.

Next, we analyzed the spectra of three periods during the 2013 observation as in Fig.1, defined by bright-

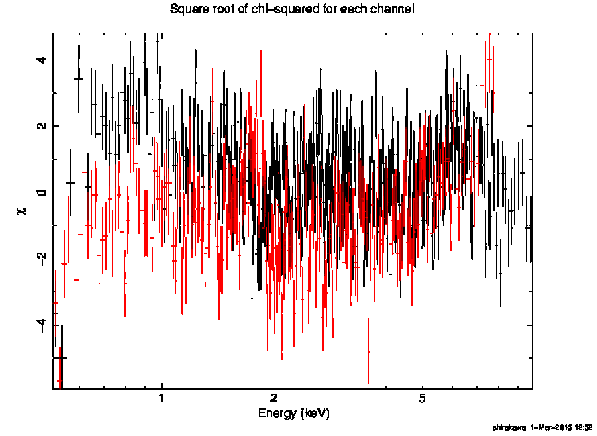


FIG. 3: Rediduals of fitting of the 1H 0323+342 spectra in 2013 with the absorbed power-law model.

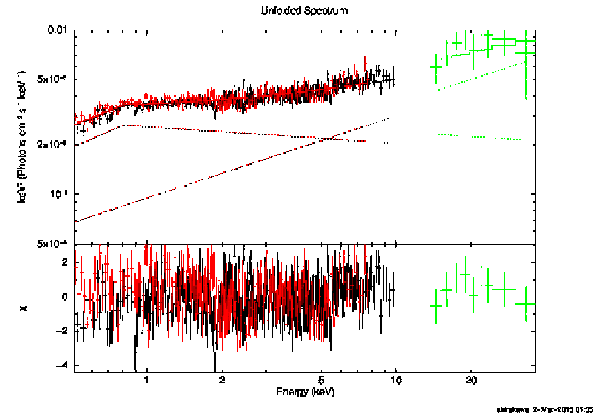


FIG. 4: Fitting the 2009 spectrum with a broken power-law plus a power-law model (jet emission model).

ness in 2013. Only a broken power-law component varied, suggesting a fast variable synchrotron emission if the jet emission model is correct. This behavior is similar to blazars.

2. Disk emission model

When we look at the residual fitted with jet emission model in 2013 (Fig.5) in detail, there is a feature like a broad Fe line around 6 keV. Therefore, we fit the 2013 spectrum with an additional Fe-K line

	photon index 1	breaking energy (keV)	photon index 2	photon index	χ^2/dof
2009	1.3 ± 0.1	0.80 ± 0.03	2.1(fix)	1.5(fix)	602.10/496
2013	0.33 ± 0.36	0.63 ± 0.02	2.1(fix)	1.5(fix)	975.22/536

TABLE I: Fitting parameters of jet emission model in 2009 and 2013

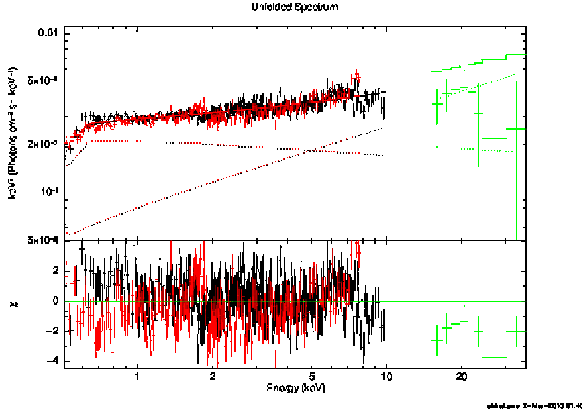


FIG. 5: Fitting the 2013 spectrum with a broken power-law plus a power-law model (jet emission model).

($E = 6.5$ keV, width = 0.5 keV), together with the above jet emission model (Fig.6). Fe line intensity is $(1.2 \pm 0.4) \times 10^{-5}$ counts/s/cm² (2.7σ statistical significance) and $\chi^2/dof = 908.28/528$; the fit improved.

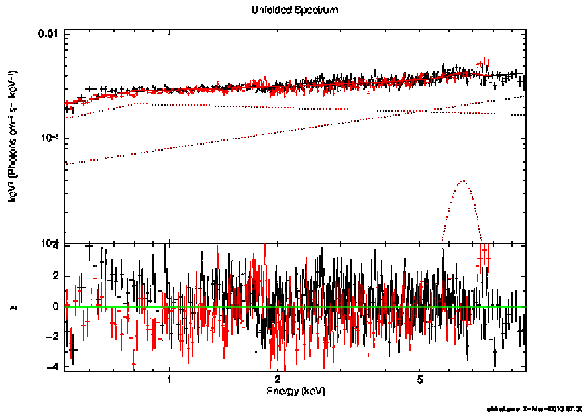


FIG. 6: Fitting with an additional Fe-K line ($E=6.5$ keV, width=0.5keV), together with the above jet emission model.

Then, we try to fit the spectra with a single power-law model plus a relativistic reflection model. The relativistic reflection component represents a reflection of a power-law incident photons by the ionized accretion disk around a rotating black hole. We call this disk emission model. In this case, the spectra are also be fitted (Fig.7 and Fig.8). The broad Fe line feature is represented by the relativistic reflection component. The broken-like feature around 0.7 keV is represented by the Fe-L line complex.

We also try to fit the spectra of two periods defined in fig 1 with disk emission model, as jet emission model. As a result, a "powerlaw" component varied. If disk model is correct, the variability is almost at-

tributed to the disk/corona component and the reflection component is stable. This behavior is similar to other Seyfert galaxies.

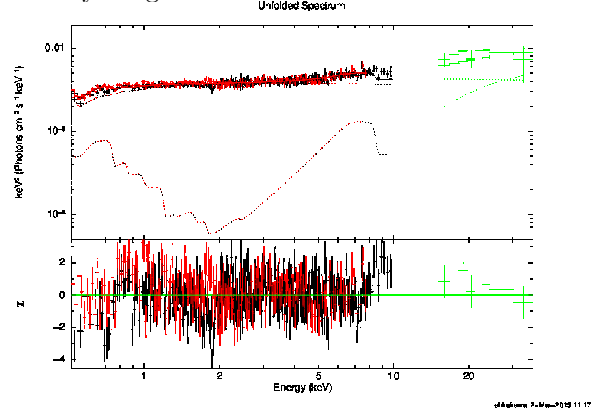


FIG. 7: Fitting the 2009 spectrum with disk emission model. See the text in detail.

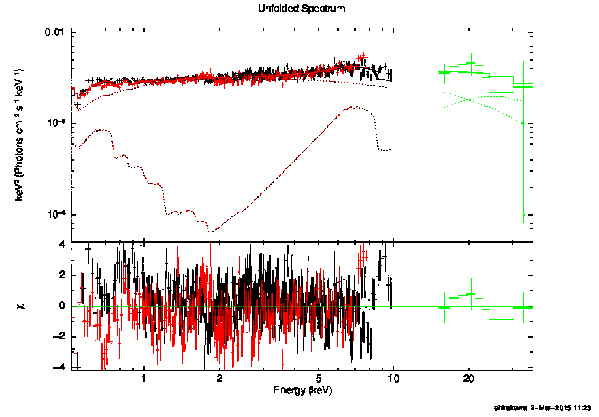


FIG. 8: Fitting the 2013 spectrum with disk emission model. See the text in detail.

III. SUMMARY AND FUTURE WORKS

We suggest that X-ray emission of 1H 0323+342 has at least two emission components, based on energy-dependence of time variability. If the X-ray emission of 1H 0323+342 is dominated by jet emission, a variable component is a synchrotron, and it is similar to other blazars. If the emission is dominated by disk/corona emission, disk/corona emission varies while disk reflection is stable, this is similar to Seyfert galaxies. We cannot distinguish these two models by current data. Therefore an extensive study by ASTRO-H observations with high energy resolution and good sensitivity in wide X-ray band is hopeful.

	cut-off energy(keV)	fold energy (keV)	photon index	a	Inclination (degree)	Fe/solar	Xi	χ^2/dof
2009	0.1(fix)	1000(fix)	2.02 ± 0.02	0.998 ± 0.02	84.3 ± 1.4	4.55 ± 1.00	10.0(fix)	640.69/493
2013	0.1(fix)	20(fix)	1.92 ± 0.017	0.998 ± 0.014	84.6 ± 1.07	5.00 ± 1.25	10.0(fix)	984.40/534

TABLE II: Fitting parameters of disk emission model in 2009 and 2013

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